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ABSTRACT

Prepared as an address for educator groups, this paper provides a theoretical perspective for thinking about problems and prospects for integrating microcomputer uses in school activities. Six major aspects of the perspective are defined: (1) the computer as general-purpose symbolic device; (2) the importance of developmental studies of children's understanding; (3) the importance of teachers and instruction; (4) the need to make computer-based learning purposive; (5) the aim of meeting educational goals effectively; and (6) the guidance of computer use by educational values. Current innovative uses of school technologies in the following areas are discussed: simulations, art and music instruction, writing skills, software for conceptual dexterity, integrated media for math and science learning, and programming languages. A list of references is included. (Author/THC)

CENTER FOR CHILDREN AND TECHNOLOGY

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PROPSECTS AND CHALLENGES FOR USING MICROCOMPUTERS IN SCHOOLS*

Roy D. Pea

Introduction

I begin by assuming that we all know that the information age has come fast upon us and that computers are here to stay. What I want to do is to present a perspective on the directions, promises and, just as importantly, problems for thinking about the uses of computers in schools, and to emphasize the critical role that educators play in the evolution of this process--of finding the most fruitful fits among computers, learning, and the creative process. I plan to make four general points, which I will first summarize briefly.

The first point is that the microcomputer, unlike any other educational medium, is a general-purpose, symbolic device that can provide open-ended tools for learning and problem solving, such as overhead projectors, films, or television. The most promising educational uses of computers and other information technologies such as videodiscs take advantage of their distinctive features in this respect.

The second point expresses a central goal for educational computing. We should work to bridge the gaps between what children do in school with microcomputers and what adults do with them in the world, in order to provide more purpose and meaning to children's learning activities. A key means to this goal is a focus on computers as tools for solving problems.

The third point conveys a recent major shift in the predominant problems with educational technologies. Whereas, in earlier times, the state of the art in computer technology was the problem, with tools

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weaker than many educators' imaginations, today the tools are quite powerful. The key problem now is that of applying the technology effectively in order to meet educational goals (e.g., Feurzeig, Horwitz & Nickerson, 1981), for many current uses of technology do not achieve them. In particular, we must not lose sight of the fact that uses of microcomputers in schools are guided by goals stemming from the values we possess, conveyed as the "aims of education." Given the remarkable history of American education and the Jeffersonian goal of universal education, these values should not be prescribed by software and computer companies, as they commonly are today, but rather by the educational community, among whom I include all the stakeholders in the educational process--parents, teachers, administrators, psychologists, and others.

The last point is more in the nature of a reminder--one of importance but not to be developed in this paper. As we use computers in schools, we should remember what we know about children and the systematic changes in their abilities, interests, and thinking as they grow older. We should also not forget what we know about teaching and its special role in education. Developmental psychology and cognitive science have each provided us with seminal knowledge about the active, hypothesis-driven character of learning, remembering, and understanding (e.g., Brown, Bransford, Ferrara & Campione, 1983), and what provides children with motivation for learning (such as play, games, and purposeful activities). The current optimism among software designers about educational roles for microcomputer software derives mainly from the belief, not very sensitive to those developmental findings, that they will make more children more intelligent quickly and effortlessly. And the roles of teachers as managers of classroom learning are too often ignored.

To make these points more clearly, I will first provide a brief, topical overview of uses of computer technology available for education today.

Microcomputer Landscapes

There is a clear continuum of microcomputer uses in education, as many have noted, from directive, computer-assisted instruction (CAI) to explorative uses of computers, such as the Logo programming environment (Papert, 1980). The key issue that defines this continuum is who is in control of the learning. The connections of educational uses of microcomputers to underlying philosophies and values of education quickly become apparent. Although we cannot do justice to the complexities of these relationships here (e.g., Kohlberg & Mayer, 1972; Langer, 1969), we may roughly distinguish three principal educational ideologies that correspond to three basic metaphors for development: the child-centered romantic school based on the metaphor of mental development through natural growth; the society-centered cultural transmission school, which views mind on the metaphor of machine or tabula rasa upon which education inscribes its marks; and the progressivism associated with Dewey and Piaget, whose principle metaphor is one in which mind develops through a dialogue between organism and environment.

Traditional directive uses of educational technologies as "learning machines" for drill and practice of basic skills are the prototypes of the cultural transmission ideology, while the frequent use of the Logo programming environment as a "stand-alone center" in the classroom is perhaps the closest modern-day software prototype of the romantic tradition, even though Papert (1980) cites affinities to Piaget's developmental theory. Progressivism may regretfully be found in few places. Salient examples are the use of business and spreadsheet tool programs, such as VisiCalc, to hypothetically test the costs and benefits of different budgeting options, and the better "mixed initiative systems" that embody didactic and cognitive conflict-provoking methods for promoting intellectual growth (Feurzeig et al., 1981).

"Mixed initiative" systems (MIS) are those where both student and software system can initiate tutorial conversation by asking questions. They thus mix the initiatives of the child and the computer. Such systems are highly promising, since they are close to what we know of how students learn most effectively, where knowledge is knowing how, not only knowing that (Anderson, 1982). Socratic methods of teaching through tutorial dialogue are individualized and may be adapted to each learner (Collins & Stevens, 1982), but they are very expensive since so much individual attention is offered. So far, the MISs embodying these didactic methods have been used mainly with students in high school, college, and postgraduate programs (e.g., Barr & Feigenbaum, 1982, Section IX; Feurzeig et al., 1981; Gable & Page, 1980; Pea, 1984), but could in principle be extended to the K-12 populations. These systems are at the cutting edge of the field of artificial intelligence, where computer programs are developed that model problem-solving behavior, in this case diagnoses of what a student understands about a problem domain, which we would normally designate as human (Barr & Feigenbaum, 1982, Sections VII-X). The core of future MISs involves what have been described as "expert systems." These complex software systems simulate problem solving by humans for specific areas of knowledge, such as internal medicine, and current uses vary from medical diagnosis to electronic circuitry design to mineral prospecting (e.g., Buchanan, 1982). Since they are developed for use by experts in these fields, they must be adapted for use in education, but the future of Intelligent CAI (ICAI) depends on further development in this area. Such systems currently require large amounts of computer memory beyond the capabilities of current microcomputers, but attainable within five years for desktop machines (Lesgold & Reif, 1982). Such work offers some of the brightest and most exciting prospects for education in the years ahead. As one example of ICAI (Stevens & Steinberg, 1981), conceptual frameworks have been developed for selecting and generating different types of explanations for how physical systems function, such as physical plants (or the body, or engines) that may be used by intelligent CAI systems to help bring about appropriate mental models in learners.

Point One: Microcomputer as Tool

In describing the microcomputer as providing open-ended tools for learning and problem solving, I have used "tools" in Bruner's sense, "as amplifiers of human capacities and implementers of human activity" (1966, p. 81). For example, the philosopher Daniel Dennett (1982) suggests that computers have magnified our imaginations, both through extending the range of our senses (as it already has in domains as diverse as mathematics, art, science, and history), and by enlarging our stock of concepts for thinking. Many current uses of microcomputers in education, such as for mechanized drill and practice or electronic pageturner, serve as tools in only a weak sense, since they implement only the most menial and unimaginative aspects of teaching. Most current examples of powerful computer tools would need to be drawn from business software, as in the powerful electronic worksheets such as VisiCalc, or the various database management systems, or writing tools such as word processors, on-line thesauri, and spelling and grammar checkers.

This point becomes clear when we ask what is distinctive about computers as tools for learning. Some of their key features as providers of learning tools are:

accurate, fast, and efficient storage, access, and updating of large quantities of information;

rapid and informative feedback on one's problem-solving attempts, whether running programs or instructional systems;

capability to engage in simulations of future events that would be impossible, costly, or dangerous in the real world because of the complexity of information required to construct various alternative and hypothetical scenarios.

On the last point, as the ads for the powerful electronic worksheet program VisiCalc note:

> Its speed and versatility make it easy for you to explore more alternatives. You can ask "what if?"...just change any number in your program and instantly, the VisiCalc program recalculates all the numbers and displays the new results. So you can readily analyze the impact of decisions before you make them.

Tools of this type, which facilitate and support hypothetical thought, are one of the most essential uses of the computer available in the adult world, yet they are rarely utilized in schools. This paradox of the student-adult gap is worthy of closer attention.

Point Two: Close Gaps Between Computer Use by Children and Adults

There is reason to believe that children will come to use computers most effectively if their world of uses overlaps closely with those of the adult world outside school. A common lament in national educational surveys is that children find it very difficult to apply what they have learned in school to the many practical problems faced outside of school. There is no reason to perpetuate this gap as children learn about new technologies. As one illustration of the current risk of replicating this problem of transfer of learning for computer use, Kurland (1983a) notes:

> In a recent survey, Electronic Learning magazine (October 1982) asked 2,000 teachers and administrators to list their favorite software programs. The programs offered by those who responded were first subdivided according to whether they were intended for classroom or professional (i.e., administrative) use. The classroom programs were then further subdivided by subject area. Of the 52 programs listed for use by students in mathematics, social studies, and English, four were simulations, three were designed to teach programming, and two were aids for writing poems. The remaining 43 could best be described as drill-and-practice programs and games. In contrast, every program that respondents favored for their own professional use was a software utility or tool--word processor, database management system, program editor, graphics editor, spreadsheet program, or file manager. Why is there such a large gap between what passes as educational software and the type of software favored by teachers? If, in society as a whole, computers are used as a tool, why is this one of the most neglected uses in the classroom? (p. 1)

If, in our current quest for universal technological literacy, we can establish such continuity from child learning to adult uses of the new technologies, the chasm-wide wound that currently separates adults' from children's uses of microcomputers would begin to heal.

Point Three: Applying the Technology Effectively

How do we apply computer technologies effectively to serve education? As you may recall, Bruner's (1966) influential theory of instruction was one that he described as "evolutionary instrumentalism," in which

> man's use of mind is dependent upon his ability to develop and use "tools" [such as language and mathematics] or "instruments" or "technologies" that make it possible for him to express and amplify his powers. (p. 24)

Updating this emphasis and playing a bit with Weston La Barre's (1954) term, we could call our current dilemma of applying computer technologies effectively as one of "designing the educational prosthetic." And, to carry Bruner's view forward in our current situation, since educational delivery systems are the primary agents of such "evolution," it places all of us today in the midst of a very important re-volution, an experiment on a grand scale, of nature and mind, that could redefine what we even mean by education. What you find in your experience as you use the available educational technologies should act as challenge and guide for better designs of the interface between learning and microcomputers.

Some of the current challenges for effectively applying new information technologies to the problems of education are the need to find broadly effective uses of existing software tools, develop quality educational software tools, and to train teachers and support them as they work to use computers and software effectively--each a complex and expensive problem to solve. Nonetheless, the prospects for learning provided by the developments in information technology are provocative and thrilling. There are many powers to harness, but few guides for configuring them to achieve educational aims. As for the powers, today we can have microcomputers interlaced with one another in communication networks that use touch-sensitive input for selecting from menus of use options, features such as voice output, speech recognition, high-resolution graphics, and quality sound synthesis, all of which can be hooked up to large satellite-based systems of shared database communications. Users are potentially able to access millions of dynamic images in the service of education through interactive videodisc systems.

What do we currently know about the effective design and use of such technologies for education? These are large questions, but some headway has been made. Some of the software features that we can expect to be important in the effective application of computer technologies as tools for learning have emerged through research on "human factors," a discipline that analyzes the interactions between people and computers. These observations are relevant to the design and use of microcomputers in education. Among other places, these features are exemplified in software developed at Bank Street College.

Functional transparency. The Bank Street Writer may be cited as an example (Kurland, 1983a). It is a popular word processing program easily learned and used by young children. The key concept behind its development is that the user should not stumble on the technology, a goal considerably aided by screen prompts and minimal use of written manuals, and usage procedures which support the mental activity the software is aimed to encourage. In the case of the Writer, these supports consist of the various kinds of revisionary processes available during writing. In the case of software packages for noncomputer-trained social scientists (e.g., in archaeology: Heite & Heite, 1982), the supports are procedures of that discipline. The science of human factors has provided many useful style guidelines for software design, such as feedback, consistency, adjustable skill level, maintenance of user's orientation or "where am I now," modular and well-documented organization (such as teacher's guides), and minimization of memory demands, all of which contribute to the functional transparency of software (Shneiderman, 1980; Simpson, 1982).

System flexibility and modifiability for different users and uses. There is a growing awareness that single-use programs, such as the first generation of word processors whose functions could not be changed by users, are too limiting. New systems allow users to define functions that suit their specific needs. There is a serious need for software that can be easily adapted to the teacher's or administrator's own uses, and "authoring systems" for this purpose to date are too linked to CAI types of programs. For educational software especially, the same program is unlikely to suit the learning needs of all children, and flexibility should be the rule. Flexibility is also desirable at the level of the classroom. Given the current resource limitations of computers and software, programs should provide some compatibility with different forms of classroom management (e.g., class size, individual children, groups).

Goal compatibility. Do the computer uses capture children's interest and relate to their goals? If so, children will be encouraged, as are adults when they learn best, to learn and create as a means to some other end. This point is essential if we take John Dewey seriously when he asserts that

> our conceptual equipment is a body of instruments that we have devised and constructed ourselves, under the pressure of our own needs and purposes. (Quinton, 1977, p. 4)

Dewey's original definition of thinking expressed his view very well:

> To me it appears as sure a psychological as biological principle that men [and women] go on thinking only because of practical friction or strain somewhere, that thinking is essentially the solution of tension. (1894, p. 408)

Individual differences. Connected to this point is the array of individual differences we find in how children learn best. Ideally, microcomputer environments for learning should be flexible enough to allow the adaptation of different branches of methods and materials to these individual differences, with many routes available to achieve the educational aims. We would never rigidly constrain ourselves to one path when we travel, and the flexibility of "mental travel" is a feature of education that should be available to children.

Content accuracy. This software feature varies by domain, of course, but its central aspect is that the knowledge or procedures the software aims to convey should not distort what is known. Many current educational software programs, such as those aimed at science instruction, are not appropriately informed by advances in our understanding of physical phenomena in the past several decades.

Developmental appropriateness. Educational software should also be developmentally appropriate, in that it is neither too simple nor too complex for the child's level of understanding. At the same time, however, conceptually innovative software may provide new instructional methods that enhance learning, so this guideline should not be interpreted rigidly. The test will ultimately be an empirical one: Are children learning what one hopes in their interchanges with the materials provided by the software?

There are also developmental issues involved in the textual complexity of instructions on how to use software or to program, and many other issues of conceptual understanding that are age-linked but frequently ignored in the design and use of software. We need to make "head-fitting" software for children, software that will dovetail with their problem-solving needs and natural ways of thinking at different ages --not software that requires a separate course of instruction so that children may learn how to overcome the variety of cognitive obstacles characteristic of poorly designed systems. The call for software systems that take heed of such issues of "cognitive engineering" (e.g., Norman, 1982) is a fairly recent one, and is rarely observed in the design of educational software.

So how does the educator work toward more effective applications of information technologies in schools? Recognizing the magnitude of the problem, and ways of having influence, are two major inroads. On the magnitude of the problem, as much as 95% of the microsoftware available today is directive CAI courseware, supporting already existing curricula in schools, such as percentages and integer arithmetic in math, vocabulary and sentence composition and decomposition drills in language arts, and "fact" programs in the sciences or social studies. There is currently too much replication of everyday drill and practice, in which the computer becomes an expensive page turner, a flashcard robot, a fact-delivery system. Mechanized lesson delivery by CAI programs, the common darling of arguments for cost effectiveness in schools, is not a panacea for the learning of the future. Much more emphasis is needed on software as tools for learning, as providers of learning and problem-solving environments. We can designate this currently bad state of affairs as a result of the "marketing paradox," an epidemic in the creation of educational software. What gets sold is what people say they want, and what they say they want is what they know gets sold. To break this vicious paradox, educators will want to develop a software "aesthetic," to break preestablished molds and push for new industry standards that utilize the computer's great potential. The dimensions of such a software aesthetic are pinpointed throughout this paper and may best be conveyed through the examples of the next section.

As part of this process of finding effective applications of technology, educators will also want to critique existing educational software. Since such software is usually not designed by educators, their commonsense evaluations are important: Who will use the software and for what purposes? Communication among educational users of software is important for finding effective uses, and should influence the software design process itself. Educator activism will be necessary to push the frontiers of software quality and to find new and appropriate uses of computers in educational settings.

But activism will depend upon teacher education. Teachers and administrators need to understand the options: What are the ways and means by which uses of microcomputers might benefit education? How could software serve the needs of teaching and learning? Educators need both basic understanding of the types of software available and to engage in critical thinking about imaginable types that are not currently implemented. Inservice programs are direly needed to continue education for teachers who use computers in their classrooms, to update their knowledge and provide forums for their creative and effective use (Derringer, 1981; Sheingold, Kane & Endreweit, 1983).

Exemplary Uses of Computers as Tools for Learning

It is always useful to see points embodied in examples, and talk of design principles is just too abstract. In the following cases, we have covered three points in which the distinctive features of computers that allow their use as tools for thinking are highlighted, the gap between school and worldly uses of computers is bridged, and some effective applications of technology to problems of education are described.

Simulations. A simulation provides a model of a real-world or hypothetical situation. At their best, simulations provide exceptionally vital tools for learning through experimentation and hypothesis testing. Educational simulation or modelling has rich potential as a tool for learning (Bork, 1980; Tinker, 1981; and see listings in Horn, 1977), or a context for games under student control (Wanner, 1982). Many simulations for complex real-world events are available in economics, history, political science, physics, chemistry, and biology. Some of the more dramatic ones today are simulations of flight, of establishing a space colony, of a pond's ecosystem, and of a nuclear power plant meltdown. One particularly exciting aspect of simulations is their use as tools for decision making. Various alternative courses of action may be simulated and then evaluated, since one may see the longterm consequences of particular decisions or conditions. In this regard, microcomputers have radically changed the way budgeting is thought about, as VisiCalc and other financial planning software have demonstrated. Large quantities of data may be used in this way to engage in systematic exploration of different hypothetical situations that would have been tedious and, in many cases, impossible without computer capabilities (e.g., Dethlefsen & Moody, 1982).

Art and music. The art (hi-resolution graphics and graphics tablets) and music (quality sound synthesis) capabilities of computers are very important because they allow composition without physical dexterity. Shapes and melodies can be easily created, edited, and used repeatedly as parts of other compositions. State-of-the-art systems in graphic design are now standard fare in architectural work. These computer capabilities also allow rich presentation for interactive software systems involving complex concepts and phenomena such as math equations, maps, physics and chemistry phenomena, and geometry.

Writing is a complex skill, for there are many component abilities and cognitive processes that characterize the problem-solving that expert writers engage in (e.g., Flower & Hayes, 1981; Bereiter & Scardamalia, 1982). In one major writing style, much of the high-level activity involves concocting and refining elaborate plans for text generation. A program called "Storymaker" (commercially available as "Textman" from Dell Publishing) exercises children's abilities to make textual inferences and evaluations through constructing a story from various nodes of storylines which are potentials for continuation. Jim Levin and colleagues at UCSD have developed a related system for story building and other writing activities (Levin, Boruta & Vasconcellos, 1983).

In another extensive software package for school writing, Quill (Collins, Bruce & Rubin, 1982) provides a text editor, a publication system, a message system, an information storage system, and kits to help students create activities for other students to participate in. Different research teams are now developing various levels of electronic prompts for sophisticated writing environments that may be adapted for children; such prompts may involve elements of style, grammar, text cohesiveness, and issues such as spelling and punctuation. Research psychologists studying the development of writing skills are starting to work together with those who design computer writing environments, and we may expect exciting developments in this area within the next several years.

Software for conceptual dexterity. As you can see, the creative emphasis for art, music, and writing may be expressed as a motto: "Don't let the hands get in the way of the mind." Although concrete sensory experience is important for learning, a child's current level of manual dexterity should not act as an obstacle to the development of conceptual dexterity. Using microcomputer technology allows us--if we so wish--to bypass the low levels of implementation, such as sentence part drills, spelling, and handwriting, and allows the spotlight to shine on the child's creative and fluid processes of design. To return to the theme of microcomputer as tool or cognitive amplifier, here we see the energies of the child's mind put to conceptual work, rather than implementing ideas, a mechanical process in far too many instances.

Integrated media for math and science learning. The Bank Street College Project in Science and Mathematics Education (PSME), funded by the U.S. Department of Education and CBS, provides a robust model for integrating different information technologies in the service of science, math, and microtechnology education in late grade school and junior high. Problems of classroom use, teacher training, and children's understanding have all played formative roles in the development of materials. From the central theme of studying whales during the seafaring voyage of a boat called the Mimi, an interlocking matrix of a nationally broadcast television series, tool software, print materials and, ultimately, interactive videodiscs is being developed for broad dissemination and use in schools. Adults use computers in science as tools for data gathering, storage, display, and analysis, and children are introduced to science, math, and computer technologies in the context of the practical activities faced during the whale studies. Two pieces of software to be used in this package will help illustrate the main themes:

1. Temperature Probe is a software tool that demonstratess how temperature relates to the whale's interactions with its environment. Created by Dr. Robert Tinker and colleagues at Technical Education Resource Centers (TERC), Probe enables children to use the microcomputer in combination with a thermal sensing device to collect and display temperature data and their changes over time in various forms --from a single thermometer, to multiple thermometers which sample temperature at specifiable intervals, to a continuous graph of change of temperature over time, or bar graphs representing temperature versus time. Students and their teacher may also work together to calibrate the thermistor against an everyday thermometer, and thus explore the concepts of scales, units, and errors of measurement. Current work is expanding this software design strategy to sensing devices for sound and light, so that Probe will serve as a toolkit of microelectronic laboratory instruments.

2. Rescue Mission is a navigation simulation game that children play in teams, or "crews," in which they learn to use microcomputer models of navigational instruments such as radar and compasses to find a vessel and guide it to a specific place to save a trapped whale. Math, physics, and earth science concepts must be learned in order to play the game effectively, and ancillary programs train the students in the use of the instruments. Such activities as triangulation of directional bearings to find position, and estimations of speed, time, and distance of travel are all part of finding the whale's spatial coordinates. The use of cooperative groups for problem solving in this software educational game is supported by studies indicating that cooperative group structure is highly effective for teaching cognitive skills (Johnson et al., 1982), and other research showing that children spontaneously choose to engage in extensive amounts of peer collaborative activities when learning to program microcomputers (Hawkins et al., 1982). Other computer games are also being developed in the Bank Street PSME for introducing the basic concepts of computation and programming to children.

Programming languages. Where do programming languages fit into this picture of educational software? It is a central fact that programming languages are rich and expressive tools for *applications*, not to be learned as ends in themselves as is so often conveyed in precollege education. It is easy to become quagmired in technical squabbles over the "best programming language" to use when that decision fundamentally depends on the purposes of using it. Perhaps the most important features of programming involve the need to define a specific problem, to analyze it into component subproblems, and to work on solving these subproblems by first designing a *plan* for program design, then writing logically sequenced instructions in the programming language that tell the computer what operations to execute, and in what order. Such programs are written as tools for solving specific problems in a content area, such as mathematics, language arts, or architectural design. There is currently little available in the way of pedagogy or curriculum materials for learning to program that takes heed of what is known about children's conceptual development and substantive interests. Nonetheless, there are good and bad methods of teaching programming, as is true for other subjects (e.g., Luehrmann, 1982), and the attention given to which programming language is best for children to learn misses the central point that programming itself (as well as other computing activities) needs to be thought of in terms of a more general developmental framework. We must ask: Programming for what ends? (Pea & Kurland, 1983). For computer literacy? To promote thinking skills that may be encouraged by the intellectual rigors of programming? For writing application programs in specific problem areas for immediate use? Most, if not all, programming languages are better suited for writing programs in some application areas than in others. For future employment? Answers to these questions will radically affect the content and methods of children's experiences in programming.

New Vistas

One aim of a theory of instruction should be to optimize learning through arranging learning environments. A major question then follows: Optimal according to what criteria? Surely two of the criteria Bruner (1966) has posed in his theory of instruction are important ones: to optimize *transfer* of information to new situations, and to optimize *retrievability* of information (pp. 37-38). As far as the first aim is concerned, the current stress in cognitive psychology of the central roles of metaphor and analogy in learning and thinking could be usefully exploited in the design of innovative software tools or computer-enhanced learning environments. Further, teachers can exploit the rich and precise procedural capacities afforded by computer programs to convey an important alternative form of representation for problem solving. For example, one can write procedures in the Logo programming language to draw shapes, in addition to using pattern blocks or drawing by hand. Recognizing this plurality of problem embodiments--a central learning heuristic in the works of Dewey and Bruner--should help in the learning process by (1) decontexting the knowledge from specific sensory experiences and rendering it better remembered and understood; and (2) by providing another language of imagery props to call on during problem-solving efforts.

We may also note a changing climate in the delivery stations for education and learning that could help create greater transfer between in-school and out-of-school learning. Traditional school subjects are increasingly being addressed and significant learning taking place outside the schools: at camps, museums, and through programming, studying, and networking with home computers at home and the storefront. We need to think about ways of ensuring quality education in those settings as well, and interrelating in-school and out-of-school computer-based learning experiences. Furthermore, the computer learning tools for the severely disabled open promising avenues for their access to the powers of the microcomputer. Other groups are currently working on software systems that will support the deaf, the blind, and the learning disabled in their learning endeavors throughout the lifespan. To make the underlying point most generally, the essential goal of <u>equity</u> of computer access and software learnability for all social classes and races is an utmost priority. At the current time, there are radical and predictable imbalances in who is working with microcomputers in schools, and even in who has the opportunity to assess the prospects and challenges that confront us.

With respect to the second criterion, the vistas provided by the current state of the art in interactive information retrieval systems allow learners access to wide and deep arrays of world knowledge. A byproduct of the information age has been the serious need for data management systems, efficient procedures for storing and retrieving complex databases. Little research has yet addressed how to make the procedures of access cognitively simple, for use by children, and as much to be counted upon as recall from human memory. One current portal into the banks and services of the information age is "networking," the entry of one's computer into large webs of information sharing that are already available. Data communication networks such as Telenet allow such access. To take one prominent example, an information network called "The Source" provides a service, the Education News and Information Network, through which educators can pose problems on an electronic bulletin-board called ED-NET. Responses to problems may be made by other system users and accessed later by the problem poser. Rich arrays of information (provided by different "database vendors") concerning education, including some educational software, may also be accessed through The Source, and CompuServe, a related information utility. Other databases allow access to enormous bibliographic databanks (such as Bibliographic Retrieval Services, Dialog, and Orbit). For example, Dialog holds over 40 million multiply cross-indexed records. One educationally relevant example is work by Levin and colleagues (e.g., Levin & Boruta, 1983), who are studying the work of elementary school children as they send not only electronic mail between schools in California and Alaska, becoming "on-line" penpals, but graphics, music, animation and programs to one another through computer communications networks. On a related front, Videotex provides opportunities for accessing information from a massive central computer through phone or cable. So far, the technology has been directed to provision of electronic news services, entertainment, home catalogue shopping and banking, and only minimally used as an educational tool (Levine, 1982), and then as prescriptive learning games. But it could bring quality software tools to the home and school.

As another new information technology, interactive videodisc systems provide capabilities that are astounding and that immediately challenge our imagination for uses in education (e.g., Bejar, 1982; Daynes, 1982; Foley, 1982). The key feature of such systems, which link the image resources of videodiscs to the control of a computer, is the capacity to store hundreds of thousands of images on an information disk which may be called upon in any order according to the user's instructions. Wicat Systems in Utah has been developing very sophisticated tutoring systems with this technology. One system allows anyone, from novices to experts, to diagnose diseases. Another is a cell biology unit for college students which has revealed faster and more effective learning than traditional classroom methods. Other current examples which reveal the complexity and potential of this sophisticated technology are an interactive videodisc training program in cardiopulmonary resuscitation developed by the American Heart Association (Hon, 1982), and the NASA videodisc that contains 100,000 striking images of the planets Mars, Venus, Mercury, and Jupiter collected during the Mariner, Viking, and Voyager space missions. The NASA disk allows dazzling simulated tours across the surface of those planets. The user controls the speed and course with a joystick. The production of interactive videodisc systems such as these, especially if instructionally intelligent, is very costly but should drop considerably as the technology develops.

Conclusions

I have highlighted the need for tool uses of computers in education that carry forward the progressivist vision of the child as an active learner who seeks meaning through interactions. The romantic, child-centered aspect of this vision is familiar to many of you from the educational philosophy underlying the development of Logo (Papert, 1980). What may be less evident is that this stance, which only becomes vital when the spirit of societal development and not just the prescription of societal norms is figured into it, has much deeper intellectual roots. As John Dewey observed nearly a century ago (1896):

> The problem for the pupil is how to get to the standpoint of the mathematician; not how to use certain tools but how to make them; not how to carry further the manipulation of certain data, but how to get meaning into the data.

The microcomputer can serve us well in this meaning-making, but we are not there yet. There is much work to be done, but the computer offers great potential for the teacher as well as the child if they can learn what powerful options software tools offer, and can help in creating the learning environments of the future.

It is appropriate to rewrite history as it is remade through this information revolution. Dewey's (1896) words are deeply relevant today (if we replace "books" with "software") when he says that

> The first [software] written from the standpoint of one who is still coming to consciousness of the meaning of his concepts will...mark the dawn of a new day to the average student.

Let us work together to open the horizons of this new dawn.

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